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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 2/59

OPERATION BUFFALO

Target Response Tests
(Co-ordinator: E. R. Drake Seager)

Biology Group
(Group Leader: R. Scott Russell)

Part 3(a): The Effects of Blast on Dummy Men Exposed in the Open

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A.W.R.E.,
Aldermaston, Berks.

July, 1959

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Part 3(a): The Effects of Blast on Dummy Men Exposed in the Open

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Summary

See page 2.

*Now Professor of Experimental Medicine, Guy's Hospital.

Summary [redacted]

Thirty articulated dummy men clad in battledress were exposed in the open at various ranges from an approximately nominal nuclear weapon. The men were set out in three postures, prone, crouching and standing and in each posture both facing and sideways-on to the explosion. This report discusses the displacements and accelerations experienced by the dummies and attempts to assess injury both from impact and acceleration. It is concluded that severe injury would have been suffered out to 2000 ft and incapacitating injury out to 3000 ft from Ground Zero. The results are in good agreement with previous theoretical calculations. A hazard which had not been anticipated was neck injury from the drag forces on steel helmets.

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1. Introduction

The illnesses caused by γ-radiation and the potential injuries from the heat flash from atomic weapons are now widely appreciated. Less is known about the biological implications of blast.

For the purpose of studying the injury caused to man the blast may be regarded as producing two effects: the hydrostatic overpressure and the dynamic or wind pressure.

The first effect may cause injury by the compression or rupture of air containing viscera:- bowels, lungs, etc. Studies of this direct effect of blast on animals were made on Operation Buffalo and are reported elsewhere [1].

The second effect will produce displacement of personnel with subsequent injury on striking fixed objects or the ground. The present investigation is concerned with the injuries of this nature which would be experienced by men in the open. Parallel studies on dummy men in military equipment and field works are reported elsewhere.

Injury to man may also be caused by missiles carried by the blast wind or by the collapse of structures under blast loading. These aspects are not considered here.

2. Objects

2.1 General Statement

The purpose of the present studies was to investigate the displacement of personnel by the free air blast wave from Round 1 of Operation Buffalo.

2.2 Specific Aims

The only previous enquiry into this problem was a theoretical study by Liston [2], who calculated that a man weighing 12 stone standing at 1300 yd from a 20 kiloton weapon would be displaced 20 ft and suffer severe injuries. A like person at 2000 yd would be displaced 4 ft and uninjured. Liston also predicted that a man lying prone at 1300 yd would be quite safe since his displacement would be insignificant. It was desired to check these predictions experimentally.

Two modes of injury by the blast wind were envisaged for investigation:-

(1) If exposed to a sufficiently strong wind, men would move bodily and receive injuries on striking fixed objects or the ground.

(2) The wind may cause sudden jerking movements of the limbs relative to the trunk. If sufficiently violent, these movements would cause dislocation of the joints or break bones.

In the event, there emerged another, somewhat unexpected, form of potential injury to military personnel from the drag forces on steel helmets.

A further object of the present tests was to provide data for comparison with the results from the dummy men inside military vehicles, guns and field defences.

3. Methods

3.1 General

Thirty dummy men were set out before the explosion of an atomic weapon of approximately 20 kilotons yield, detonated on a tower. The dummies were set out in 6 orientations to the explosion: each orientation was displayed at 5 ranges.

3.2 Description of Dummy Men

The dummies were designed to resemble men ballistically, to simulate as far as possible with inanimate objects the interaction between man and the blast wave. The model chosen for the present purposes had been designed and developed by RAE, Farnborough [3] for studies of seat ejection and restraint harnesses [4]. The dummies (see Figure 1) were regarded as virtually indestructible. Consisting basically of mild steel with cannisters for limb segments, they were manufactured so that the total weight and segment weights and the centres of gravity of the various limbs, trunk and head were all appropriate for a 6 ft man weighing 175 lb (12½ stone). The metal parts were covered with rubber foam. The limbs were articulated at hips, knees, shoulders and elbows by ¼ in. mild steel tongue and groove joints, swivelling on ½ in. mild steel bolts. There were cavities in the chest compartment and abdomen for accelerometers.

The dummies were dressed in worn service uniform: khaki shirt, battledress, socks and boots. This was specified because clothing obviously influences the drag coefficient of man exposed to the blast wave. It has been reported that clothing was torn away completely from survivors at Hiroshima and Nagasaki. The present trials would therefore also indicate the resistance of a standard army uniform to the effects of blast, heat and displacement.

Whitened belts, gaiters, pouches and steel helmets were placed on most of the dummies to assist in photographic recognition.

3.3 Instrumentation

All instrumentation was undertaken by the Instrumentation (IT) Group. Certain dummies were fitted with 3 Graseby accelerometers mutually at right angles, wedged into the chest cavity, with a control box in the abdomen [5].

Plans were made to follow the movements of the dummies by cinematography. G45 gun cameras (recording by means of periscopes) were sunk into the ground in specially designed leaded camera boxes [6].

3.4 Design of the Experiment

3.4.1 Effects of Drag Pressures on Displacement

The effects of forces acting on the dummies were to be followed by estimating the displacement of the dummies and from accelerometers and cinematograph records where these were available.

Since the effects would depend upon friction and upon the area exposed to the weapon, six postures were chosen. Standing, crouching and lying were selected as representing three stages in taking evasive action. Each of these position was duplicated, facing, or head towards, and sideways on to the weapon. Each of these six postures was exposed at five ranges: the actual layout of the displays is shown in Table 1 below. Figures 2 and 3 show typical views of sites 1 and 4 before the explosion. It will be seen that the standing and crouching dummies were supported by scaffolding. Standing dummies were retained in the vertical position by copper wire.

TABLE 1

Layout of Dummies Clad in Battledress

Site No.	Range from Ground Zero, ft	Predicted Overpressure, p.s.i.	Predicted Drag Pressure, p.s.i.	Posture of Dummy					
				Prone		Crouching		Standing	
				Facing	Sideways	Facing	Sideways	Facing	Sideways
1	1840	19	7.4	+	+				
2	2056	14	4.2	+	+				
3	2200	12	3.1	+	+	+	+		
4	2390	10	2.2	+	+	+	+	+	+
5	2656	8	1.5	+	+	+	+	+	+
6	3110	6	0.8			+	+	+	+
7	3900	4	0.35			+	+	+	+
8	6000	2	0.1					+	+

3.4.2 Effects of Blast and Displacement on Joints

When the dummies were unpacked on site, it was found that the joints were of "random looseness", it was also apparent that it would be difficult or impossible to ensure that all joints were made equally stiff. Under the circumstances it was decided to use the random state of the joints to evaluate the risks of joint dislocation and bony injury. The state of fixity of all joints was therefore graded as immoveable, stiff or quite loose before and after the event.

3.4.3 Steel Helmets

The forces acting on the head and neck were judged in a rough fashion by measuring the displacements of steel helmets placed on the dummies with straps under the chin.

3.4.4 Missiles

Clothing was examined after the explosion for lacerations by missiles.

3.4.5 Heat Flash

Clothing was examined after the event for evidence of the effects of the heat flash. The sequence of events in scorching battledress was also followed cinematographically at site Nos. 6, 7 and 8.

3.5 Measurements

The displacement of each dummy was determined by measurement from 4 in. nails driven into the ground at each starting point. These nails were easily located after the explosion. (Additional precautions were also taken, needlessly as it proved, by recording the bearings of each dummy from a pair of camera boxes before the explosion.)

Displacements were usually measured in terms of the centre of gravity of the dummies, taken as the midpoint of the horizontal section at the waist. However, in the case of certain dummies at further ranges, it was clear that the mere act of toppling over would create a displacement of the centre of gravity of about 3 ft. In such cases, it was decided that the measurements should allow for the fall.

Effects on joints were judged by re-examination after the event. Only gross changes from one category to another were recorded as an effect.

The effects of the explosion, and displacement, on the clothing were recorded after inspection.

The displacement of the steel helmets was measured from the starting points, described above.

Accelerometer records could be analysed for peak accelerations only.

Cinematograph records were analysed for effects of heat flash on clothing, for time of arrival of shock wave and for information about displacement.

For subsequent analyses, it was necessary to determine the areas presented by the dummies to the explosion. This was done by photographing a dressed dummy against a suitably squared background from a distance of 60 ft. The area of the dummy outline was then determined from tracings taken from the photograph. By these means, the presented area of a prone dummy with heat towards the explosion was found to approximate closely to 1 ft^2, the presented area of a prone, crouching or standing dummy sideways on approximated to 5 ft^2. Dummies crouching, facing the explosion presented an area of about 4 ft^2 and standing facing the explosion, of about 10 ft^2.

4. Results

4.1 Detailed Results

The results in terms of displacements, damage to limbs and joints, the effects on clothing and steel helmets are displayed in detail in Appendix A. The peak accelerations recorded by the accelerometers are shown in Appendix B. Selected frames from cinematograph records are included among the figures, and are referred to and described in the text.

4.2 Displacements of Dummy Men

The views shown in Figures 4 and 5 exemplify the effects of the blast wave in displacing the dummy men depicted in Figures 2 and 3.

TABLE 2

Displacements Classified According to Drag Pressure, Posture and Orientation

Site No.	Drag Pressure, p.s.i.	Overpressure, p.s.i.	Posture					
			Prone		Crouching		Standing	
			Facing, ft	Sideways, ft	Facing, ft	Sideways, ft	Facing, ft	Sideways, ft
1	7.4	18†	42	66	-	-	-	-
2	4.4	14.5	2.5	69	-	-	-	-
3	3.7	12	2	20	15	39	-	-
4	2.7	10	1	8	16	18	33	20
5	1.9	8.5	1	24*	9	9	30	16
6	1	6.4	-	-	6	9	16	10
7	0.43	4.3	-	-	1	3(4)	4(7)	3(6)
8	0.11	2.4	-	-	-	-	2(5)	0

*This dummy was sited on firm rocky ground. All others were sited on soft ground.

†Multiple peaks in overpressure record.

Table 2 gives the displacements of the various dummies according to posture and range, together with estimated drag pressures which occurred at the various displays.

In certain cases additional information is given in parenthesis: these figures represent the actual displacements of the centres of gravity, which were corrected for displacement through the final toppling over from the standing or crouching position.

4.3 Accelerometer Results

Electrical circuit failure prevented time resolution of accelerometer records and only peak accelerations in the vertical, lateral and longitudinal planes are available for analysis. The peak accelerations in the plane of initial displacements for the instrumented dummies have been abstracted from the detailed information in Appendix B and are tabulated below (see Table 3) for comparison with the displacements shown in Table 2. (Note that not all dummies were instrumented with accelerometers.)

TABLE 3

Maximal Positive Accelerations Recorded in the Planes of Initial Displacement of the Dummy Men Exposed in the Open

Site No.	Posture and Plane					
	Prone		Crouching		Standing	
	Facing Vertical, g	Sideways Lateral, g	Facing Vertical, g	Sideways Lateral, g	Facing Longitudinal, g	Sideways Lateral, g
1	14	14				
3	9	12	7	19		
4					26	24
5	4	7	11	13		
6					*	55
7			6	7		
8					13	3

*Burned Out.

4.4 Calculated Maximum Decelerations

It is presumed that the maximum decelerations recorded occurred at the terminal collision with the ground. These results might give some indication of the severity of damage sustained. Maximum decelerations were therefore calculated from the data given in Appendix B as

$$\sqrt{La^2 + Ve^2 + Lo^2},$$

where La = maximal recorded lateral deceleration;

Ve = maximal recorded vertical deceleration;

Lo = maximal recorded longitudinal deceleration.

Table 4 below shows the results of these calculations classified according to site, posture and orientation.

TABLE 4

Maximal Decelerations Derived from Accelerometer Results, Classified According to Site, Posture and Orientation

Site No.	Posture					
	Prone		Crouching		Standing	
	Facing, g	Sideways, g	Facing, g	Sideways, g	Facing, g	Sideways, g
1	18	35				
3	18	17	17	15		
4					53	11
5	12	17	26	11		
6					*	22
7			0	26		
8					16	5

*Burned Out

4.5 Cinematograph Records

4.5.1 Results Obtained

Three cinematograph records were sufficiently clear (unfogged) to depict events. These refer to site Nos. 6, 7 and 8. Unfortunately, only at the furthest site (8) is it possible to follow the effects of the blast wave.

4.5.2 Site 6

The camera at site No. 6 was operating at 64 frames/sec. The total heat dose at this site was 23 cal/cm^2, the γ-radiation dose was 2000 r. Various frames have been selected for presentation in Figure 9. The records show: the site just before detonation; the first light (1/64 sec); first signs of scorching of battledress (11/64 sec); obvious scorching (16/64 sec); smoking of battledress and overall popcorn effect (32/64 sec). The field of view was completely obscurred by mist and dust at 1 sec: the blast wave did not reach this site until F + 1.5 sec.

4.5.3 Site 7

The camera at site No. 7 was operating at 19 frames/sec. The total heat dose was 14 cal/cm^2, and the γ-radiation dose 340 r. Various frames have been selected for presentation in Figure 10. The records show the site just before detonation, first light, the beginning of scorching of battledress (5/19 sec); steaming and scorching of battledress and popcorn effects on ground (9/19 sec), at which fine black smoke was obscuring the face of one dummy (see Figure 10(iv)). Scorching of the material continued and mist rose from the ground until the view was obscured at 1¾ sec. The blast wave arrived at F + 2.1 sec. These findings and the results at site No. 6 raise questions as to the proportion of the total heat effective on cloth samples which was attenuated by steam and smoke.

4.5.4 Site 8

The camera at site No. 8 was operating at 19 frames/sec. The total heat dose at this range was 5.8 cal/cm^2 and the γ-radiation dose was 17 r. Various frames have been selected in Figure 11. The record shows the site just before detonation first light, the first detectable scorching of hats (4/19 sec), of battledress (10/19 sec), general scorching (15/19 sec), scorching and steaming from the ground (1 sec). Steaming of the ground began to subside at 1½ sec. The blast wave reached this site at F + 3.9 sec, and its arrival was manifest in the record by the removal of the dummys' hats. The blast wave caused a smooth movement of the standing facing dummy, who was displaced backwards and turned towards his left slightly before subsiding onto the ground. The standing sideways dummy was displaced slightly away from the explosion, but did not fall from his scaffolding.

4.6 Joint Changes

The changes in joints shown in Appendix A have been classified according to posture and orientation in Table 5 below.

TABLE 5

Number of Joints Affected in Different Postures and Orientations

Joint	Posture						Totals
	Prone		Crouching		Standing		
	Facing	Sideways	Facing	Sideways	Facing	Sideways	
Knees	1	2	0	1	1	4	9
Hips	2*	4*	2	0	1	1	10
Elbows	5	2	3	2	1	1	14
Shoulders	3*	3	1	2	2	3	14
Totals	11	11	6	5	5	9	47

*Includes a broken joint.

4.7 Displacement of Steel Helmets

The displacement of steel helmets exposed in conjunction with the prone and crouching dummies are shown in Table 6. Steel helmets could not be exposed with the standing dummies.

TABLE 6

Displacements of Steel Helmets

Predicted Blast Data*				Posture of Dummy			
				Prone		Crouching	
Site No.	Overpressure, p.s.i.	Wind Speed, miles/h	Drag, p.s.i.	Facing, ft	Sideways, ft	Facing, ft	Sideways, ft
1	19	560	7.4	96	276	-	-
2	14	390	4.2	0	249	-	-
[redacted]	12	330	3.1	0	62	11	100
[redacted]	10	300	2.2	0	24	0	103
5	8	240	1.5	0	0	0	121
[redacted]	6	200	0.81	-	-	0	132
7	4	140	0.35	-	-	0	0

*For measured overpressure and drag pressure see Table 2.

5. Discussion

5.1 Displacements

It is interesting to note that, for any drag pressure, the displacement of the dummies oriented sideways-on is of the same order, irrespective of the posture. This implies that friction with the ground did not impede take-off of the prone and crouching dummies.

Table 2 shows that the head forward position makes a difference in the subsequent displacement. In the case of prone dummies, this difference is by a factor of 2/3 to 8 (we neglect the spurious 24 ft displacement of the sideways prone dummy sited on rocky ground). The head forward position also reduced the displacement of crouching dummies, by a factor of up to 3. In the standing dummies, facing the explosion is obviously disadvantageous since it approximately doubles the area exposed in comparison with the sideways-on position. This difference is reflected in the results, which show greater displacement for the facing than sideways-on positions.

From (i) the drag pressure, (ii) the surface area presented to the explosion, and (iii) the duration of the blast wind, it is possible to calculate impulse. This is proportional to the product of (i) × (ii) × (iii).

Impulse can be correlated with displacement as was done at previous trials for vehicles.

Using the figures for presented area given in Section 3.5 above, together with the data available for drag pressures and wind durations, it is possible to construct a curve for the relationship between impulse and displacement. Figure 6 shows this relationship. The solid line is the regression curve calculated to fit these results. It has the form

$$\text{displacement, in feet} = \frac{(A \times P \times T)^{1.5}}{1660},$$

where A = presented area, in^2;

P = Peak drag pressure, p.s.i.;

T = duration of positive phase, sec.

The dotted lines in Figure 8 show the 95% confidence limits based on the foregoing data.

5.2 Accelerations

The prone dummies show a graded reduction in peak accelerations as the range from Ground Zero increased. This was also true for the crouching sideways dummies and the two standing facing dummies (that at site 6 was burned out). Unexpectedly low acceleration is recorded for the crouching facing dummy at site No. 3: reference to Table 2 shows that this was associated with a relatively small displacement. In contrast, very high acceleration was found with the standing sideways dummy at site No. 6. This may be attributable to a collision occurring subsequent to the initial displacement acceleration.

It is of interest to note that the higher accelerations are recorded for standing dummies, and not with the prone dummies at site No. 1 which nevertheless suffered considerably greater displacements. Although the lower accelerations of the prone and crouching dummies could be explained by damping due to friction at points of contact with the ground, it was important to seek a theoretical basis for the observed accelerometer records by comparing the experimental results with calculated initial accelerations.

To calculate the initial accelerations, we have assumed that the shock front departs around the dummies too quickly to have any effect on the accelerations recorded.

Then, if the maximum dynamic pressure, occurring just behind the shock front is P_d, the instantaneous force applied to the dummies becomes

$$AC_DP_d,$$

where A = area exposed;

C_D is the drag coefficient.

If the instantaneous acceleration is $\ddot{x}$

$$AC_DP_d = \frac{W}{g}\ddot{x},$$

where W is the weight of the body.

Assuming that C_D is unity,

$$\ddot{x} = \frac{AP_d}{W} \text{ g.}$$

To simplify the present case, if W = 180 lb, A = area of presentation in ft^2 and P_d is in p.s.i.,

$$\ddot{x} = \frac{4}{5} AP_d, \text{ in g.}$$

This calculation has been done for the various dummies for which accelerometer results are also available. Figure 7 compares calculated and experimental results. It will be seen that there is a positive correlation between observed and calculated results and that this correlation would have been of a high order if there had been an error of 5-6 g in all accelerometer records. It is tempting to attribute this to a systematic error in calibrating or deducing the accelerometer data, but it must be remembered that the effects of shock pressure have been ignored. Apart from this error, the analysis above indicates that the accelerometers were generally reliable in providing information about take off conditions. Figure 8 shows that there is a fair correlation between initial acceleration recording and displacement suffered.

5.3 Decelerations

The correlation between displacement and maximal decelerations is poor, no correlation can be recognized between deceleration and severity of damage to dummy. The most severe damage was caused to the prone facing dummy at site No. 1, and the prone sideways dummy at site No. 3, yet they apparently sustained decelerations only slightly in excess of that recorded for the standing facing dummy at site No. 8, and for whom we have cinematographic evidence that there was displacement of no more than 2 ft before the dummy subsided to the ground. It must be concluded therefore that, while some displacement must occur to cause injury, injury, or damage depends more upon the detailed nature of the terminal collision than upon the magnitude of the displacement or rapidity of deceleration. Within the limits of the present study, breakage of limbs must be regarded as coincidental to displacement: it cannot be judged or prognosticated from the accelerometer readings.

To sum up the accelerometer data, it may be stated that they give information in accord with events taking place at the beginning of displacement, when acceleration is occurring in a single and known direction, but that they did not provide any useful index of injury.

5.4 Cinephotograph Records

Examination of the film shows that the standing facing dummy appears to have an acceleration of some 3-4 ft sec^{-2} during the first 0.25 sec. This compares unfavourably with the maximum longitudinal acceleration of 13 g recorded by the instrument in the chest cavity. The maximum deceleration recorded in this dummy who subsided into the sitting position and then fell sideways was 12 g. This figure provides a useful index for relative severities of fall: it is clear that with the Graseby accelerometer, accelerations and decelerations of 12-13 g are unlikely to be associated with injury. It is also of interest that the dummy which did not fall suffered accelerations of 4-6 g and decelerations of 2-3 g.

5.5 Joint Changes

The prone position, with the head towards Ground Zero, resulted in displacement of only a few feet in all cases except the closest site. Nevertheless these dummies showed evidence of severe wrenching effects at the joints, especially of the upper limbs which were stretched forwards. The absence of serious bodily displacement in several of these dummies who nevertheless showed joint changes shows that the possibility of serious dislocation due to movement of limb with respect to the trunk can occur. This point does not appear to have been considered before.

Little significance should be attached to the increased incidence of joint changes among the prone series, since these dummies were exposed to considerably greater drag pressures than those in other postures.

It is of interest that the knee joints were vulnerable in the standing sideways-on position.

5.6 Clothing

All clothing on the metal dummies was seriously scorched, even to the furthest site. Some information about the sequence of events in the scorching of cloth can be gleaned from the cinematograph records. It seems not unlikely that, when worn, clothing might be subjected to rather more heat than obtained with static, inanimate dummies. Real casualties would have been moving during the first stages after the explosion and thereby presumably diminishing the protective action of the early steaming from their clothing, shown so clearly in the records from site No. 7.

All clothing out to 3110 ft was severely damaged by heat and subsequent blast effects: it seems unlikely to be serviceable for fighting for survivors exposed to conditions similar to those at site No. 6 or closer to Ground Zero. Beyond and out to 3900 ft, battledress was badly scorched and showed small surface tears suggestive of missiles, but was not torn by the blast wind. The impression was formed that this uniform would not have been serviceable for action. At 6000 ft, the uniform was scorched and somewhat friable, but would have stood some wear for a short time: it was not, however, of normal strength.

5.7 Displacement of Steel Helmets

The displacement figures shown in Table 6 exceeded expectations when this part of the present trial was inaugurated. The displacements for dummies lying prone, exposed sideways-on, indicate the magnitude of the forces which would tend to rotate the head on the shoulder at these ranges. The question obviously arises as to whether these forces are sufficiently great to break or dislocate the neck, even if a steel helmet had not been worn. This is a matter for a special study.

The obvious conclusions from the findings summarized in Table 6 are:-

(1) The inadvisability of wearing the retaining strap of a steel helmet under the chin;

(2) The possibility of steel helmets being a serious missile, especially in confined spaces. It would be very important to insist on personnel taking off their steel helmets when under cover and not protected from blast effects.

5.8 Clinical Impressions

Some attempt must be made to deduce what would have been the fate of soldiers exposed in the same way as the present series of dummies.

Certain conclusions can be drawn as follows:-

(1) All such soldiers would have suffered severe flash burns on exposed skin;

(2) All such soldiers within 3500 ft (i.e., site Nos. 1-6) would have suffered serious, lethal, radiation illness;

(3) All soldiers beyond 4000 ft in open country would have suffered little or no injury from blast displacement per se;

(4) Soldiers at ranges of less than 2250 ft would probably have suffered moderate to very severe injuries from blast displacement per se. Note that three metal limbs were disarticulated in this zone;

(5) The severity of injury would have been roughly proportional to the surface area presented to the blast wave. Thus crouching and standing dummies show greater displacement than prone dummies at similar ranges. Similarly prone dummies exposed sideways-on to the explosion suffered greater displacement than prone dummies with heads towards Ground Zero.

5.9 General Discussion

Three aspects of the present trial give cause for discussion: displacement, instrumentation and the overall clinical effects of displacement.

The movements we observed for dummies standing at 3900 ft and 6000 ft are in close agreement with the predictions of Liston. He calculated that a man standing exposed to 7 p.s.i. from a 20 kiloton weapon would be displaced 20 ft, and exposed to 3 p.s.i. from a like weapon, displacement would be 4 ft. We observed displacements of 30 and 16 ft for the dummies standing facing Ground Zero at overpressures of 8.4 and 6.3 p.s.i. respectively. At overpressures of 4.3 and 2.4 p.s.i., the displacements were 4 and 2 ft.

This correspondence between theoretical and practical results suggest that Liston's assumption for the drag coefficient for a standing man (0.8) must closely approximate the true coefficient.

By exposing dummies to various pressures in different postures and in two orientations, we have been able to derive a regression equation for their displacement in terms of area presented to the blast wave, its dynamic pressure and duration. This formula is applicable to all weapons and will be modified only by evasive action, or bracing against displacement.

Of the instruments selected for the present trial, satisfactory cinematograph records would most likely have proved the most useful in assessing risks of injury. Appraisal of what the body can take in terms of displacement was much more likely to be accurate if based on motion pictures of the event, for comparison with integrated visual experience, than from records of accelerations. However, technical difficulties obscured cinematograph films, at all but the furthest sites. At site Nos. 6 and 7, the cameras recorded some extremely interesting information confirming the early stages of scorching and singeing of battledress uniform and also showed how steaming from cloth, or ground, might interfere with the arrival of the later stages of the thermal dose at the surface of materials under test. But only at a single site (No. 8) were blast effects recorded. However, this information is not without interest because the film shows minimal displacement, which can be correlated with accelerometer records.

The meters used in the present trial recorded much higher accelerations than either Liston or ourselves have deduced from calculations. We are inclined to attribute this discrepancy to calibration errors, but it must be borne in mind that the calculations neglected acceleration from the blast front itself.

Although the accelerometers gave results in fair agreement with expected values for the initial take-off accelerations, the data they provided about the final collision with the ground have proved difficult to interpret. The dummy standing facing Ground Zero at site No. 8, was displaced 2 ft and then subsided to the ground in the sitting position 2 ft behind the starting line, the accelerometer recorded decelerations of up to 12 g. This must be taken as evidence that decelerations of up to 12 g, recorded by the Graseby meter, are unlikely to be associated with injury: falls similar to the dummy's are seen repeatedly without any injury in many everyday circumstances. Indeed, falling onto soft sand, only 7 dummies of those instrumented had deceleration components in excess of 12 g. Furthermore, 3 of these 7 were in the prone position, in which posture serious injury seems unlikely for men in the open, except at the shortest ranges. Looking at the problem in another way, it may be remarked that quite high accelerations and decelerations were recorded in the standing sideways dummy which did not fall over at site No. 8. The durations of all these decelerations must have been much briefer than obtained in Lathams observations [4]: he studied tolerance to decelerations lasting 0.2 - 0.4 sec.* It must be concluded therefore that the accelerometers, without time resolution, proved of little practical value in the assessment of injury in the present trial.

Clinically, it must be borne in mind that the serious displacement effects observed have occurred well within the range of lethal γ-radiation or serious flash-burning on exposed skin. However, this does not obviate the possibility of blast displacement injuries existing by themselves. This possibility may arise from weapons of larger yield well beyond the range of γ-radiation illness. Thus the formula for displacement suggests that a standing facing dummy would be thrown 10 ft backwards 4½ miles from a 1 Megaton weapon. And with weapons of less than 100 kilotons yield, persons might be screened from the heat flash and γ-radiation dose yet emerge and suffer displacement from the blast wave a second or more after detonation.

The general clinical conclusions must be that most fighting personnel in the open within 2000 ft of a nominal bomb would suffer moderately severe injuries from displacement even if they took evasive action and got into the prone position. Equally, it is unlikely that personnel in the open would suffer serious displacement injuries beyond 3000 ft from a nominal bomb.

*It might give some idea of the magnitudes involved to mention that a body falling 3 ft freely under the influence of gravity and brought to rest in 3 in. would experience a deceleration of 12 g for about 35 msec.

By contrast, it has emerged from the other study that personnel concerned with guns, vehicles and even in earthworks could suffer much greater injuries than men in the open.

6. Conclusions

The present investigation was designed primarily to study the displacement of dummy men by the blast from Round 1 at Operation Buffalo. Analysis of the results shows that displacement was dependent upon the area presented to the blast wave, the dynamic pressure and its duration. A regression formula could be derived from the results. The findings are in good agreement with previous theoretical calculations.

Exposure of the dummies also gave some indication of the displacement injuries likely to be suffered by soldiers at various distances from the weapon. Damage to steel limbs was found after the event. From detailed examinations it is concluded that severe injuries from blast displacement would have been suffered out to 2000 ft, and that soldiers would have been incapacitated out to 3000 ft, not least by the destruction of their uniforms. It is stressed that these effects lie within the range of lethal γ-radiation and serious flash-burning injury.

The trials revealed other hazards which had not arisen from theoretical considerations, namely breakage of limbs and dislocation of joints together with hazards from steel helmets, not only to the wearer whose neck might be broken by blast effects, but also as missiles which might injure others.

It must be concluded that the cinematograph records in the present trial added information of more interest to questions of heat effects on uniforms and the ground than to the problems of displacement; however, useful records were obtained at the furthest site from the weapon.

The accelerometer records were of limited value, because of circuit failure which prevented time resolution. In these circumstances it was possible only to show a correlation between initial accelerations recorded and calculated accelerations. No correlation could be detected between decelerations recorded and the estimated severity of injury due to displacement. It is suggested that, pending more information about decelerations suffered in everyday life, photography is more likely to indicate the probable injury from a displacement than accelerometer records.

7. Recommendations

(1) Further trials of the effects of blast in displacing dummies sited on surfaces of different friction properties should be conducted.

(2) Further trials with dummies dressed in different service clothing, including greatcoats, are indicated.

(3) Since the value of accelerometers as a guide to injury remains to be proven, information about accelerations and decelerations in various circumstances, such as short falls, etc., should be studied and compared to the present results where a deceleration of 12 g was recorded for a minor fall.

(4) Cinematographic records must be photographed from an angle which minimizes obscurance by heat-flash mist from the ground.

(5) The two main practical lessons arising from the trial should be widely broadcast, as follows:-

(i) there is no substitute for the prone position in resisting the displacement effects of blast in the open;

(ii) steel helmets may cause serious injuries to the wearers and/or to others in the vicinity.

(6) The following proposition must be considered and perhaps acted upon:- the fighting efficiency of the soldier at close ranges from atomic weapons is determined by the resistance of his uniform to the effects of blast, (especially if it has been exposed to the heat flash).

8. Acknowledgments

The authors acknowledge the invaluable assistance rendered to them at Maralinga by members of the Indoctrine Force, who assisted with the dressing and emplacement of the dummies.

References

1. P. L. Krohn and J. McGregor: "Operation Buffalo - The Physiological Effects of Long-Duration Blast Waves". AWRE Report No. T3/58.

2. Maj. R. H. A. Liston, R.A.: "The Kinematic Effect of Blast on a Man in the Open". ARE Report No. 1/48, Part 6.

3. G. Lovell: RAE Technical Note Mech. Eng. No. 176 (May, 1954).

4. F. Latham: "Linear Deceleration Studies and Human Tolerance". Clinical Science, 17, 121 (1958).

5. J. F. Gilbert: "Operation Buffalo - The Accelerations Recorded on Target Response Items". AWRE Report No. T68/57.

6. O. R. Ottaway: "Operation Buffalo - The Cine-Photography of Target Response Items". AWRE Report No. T49/58.

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APPENDIX A

Results of Exposing Dummy Men to Blast

Target No	Range from Ground Zero, ft	Position	Orientation	Displacement, ft	Injuries to Limbs or Joints	Clothing Effects	Displacement of Steel Helmet, ft
T15	1840	Prone*	Head forwards	42	Right arm amputated and right leg disarticulated at hip. 1 hip and 1 elbow loosened	Badly torn and burned	96
	Firm sand	Prone*	Sideways	66	2 hips, 1 knee, 2 shoulders loosened		276
T16	2050	Prone	Head forwards	2.5	Loosening to 1 hip, elbow and shoulder	Charred and badly torn	Nil
	Firm Sand		Sideways	69	General loosening		249
T19	2200	Prone*	Head forwards	2.0	Loosening of 2 elbows and 1 shoulder	Charred and badly torn	Nil
	Firm sand	*	Sideways	20	Left leg disarticulated at hip, general loosening		
		Crouching*	Head forwards	15	Nil		23
		*	Sideways	39	Nil		100
T23	2390	Prone	Head forwards	1	Loosening of 1 elbow, 1 shoulder	Scorched and badly torn	Nil
	Very soft sand		Sideways	8	Loosening of 1 shoulder		24
		Crouching	Head forwards	16	Stiffening of 2 elbows. Loosening of 2 shoulders and 1 elbow		Nil
			Sideways	18	No change	1 scorched and badly torn	103
		Standing*	Facing	35	Loosening of 1 shoulder and 1 elbow	(Trousers blown off)	(na)
		*	Sideways	20	Loosening of 2 knees, 1 elbow, 2 shoulders	Left trouser leg blown off	(na)
T26	2656	Prone*	Head forwards	1	Nil	Scorched and badly torn	Nil
	Firm sand and rock	*	Sideways	24	Loosening of 1 knee and 2 hips		Nil
		Crouching*	Head forwards	9	Loosening of 1 elbow		Nil
		*	Sideways	9	Loosening of 1 knee	Left trouser blown away	121
		Standing	Facing	30	Loosening of 1 knee and stiffening of 1 hip	Trousers blown away	(na)
			Sideways	16	Loosening of 1 knee and 1 hip	Left trouser torn away	(na)
T36	3110	Crouching	Head forwards	6	Nil	All scorched badly torn	Nil
	Sand		Sideways	9	Loosening of 1 elbow and 1 shoulder	Badly torn	132
		Standing*	Facing	16	Completely charred by fire	Clothing gone	(na)
			Sideways	10	Loosening of 1 knee and 1 shoulder	Badly torn	(na)
T39	3900	Crouching*	Head forwards	1		Scorched otherwise little damage (small tears) as above	Nil
	Sand	*	Sideways	3†			Nil
		Standing	Facing	4† *	1 shoulder stiffened		Nil
				3†			Nil
T40	6000	Standing*	Facing	2†	Nil	Scorched	(na)
	Sand	*	Sideways	Nil	Nil	No other damage	(na)

*These dummies were instrumented with accelerometers.

†These results have been corrected to allow for the dummy falling over. The centre of gravity moved 3 ft further with standing dummies and 1 ft further with the crouching sideways dummies.

APPENDIX B

Accelerometer Results

Site No.	Orientation of Dummy	Direction of Movement	Maximum Positive g	Maximum Negative g
1	Prone facing	Long	6.75	5.75
		Lateral	7.5	15.25
		Vertical	14.25	8.25
	Prone sideways	Long	16.0	28.0
		Lateral	14.25	19.25
		Vertical	22.25	8.25
3	Prone facing	Long	16.5	11.5
		Lateral	23.0	11.25
		Vertical	9.0	7.75
	Prone sideways	Long	11.75	10.25
		Lateral	9.75	9.0
		Vertical	9.0	11.0
	Crouching facing	Long	15.75	9.75
		Lateral	10.75	10.75
		Vertical	6.75	8.75
	Crouching sideways	Long	18.5	7.25
		Lateral	11.25	7.25
		Vertical	12.75	11.25
4	Standing facing	Long	25.5	46.25
		Lateral	5.25	8.25
		Vertical	5.75	26.5
	Standing sideways	Long	-	-
		Lateral	23.75	5.0
		Vertical	0	9.57
5	Prone facing	Long	5.0	7.0
		Lateral	6.75	6.0
		Vertical	4.25	8.5
	Prone sideways	Long	13.0	5.5
		Lateral	7.25	3.25
		Vertical	6.75	15.0
	Crouching facing	Long	10.75	24.25
		Lateral	4.75	7.75
		Vertical	10.75	5.75
	Crouching sideways	Long	9.25	7.25
		Lateral	13.25	8.75
		Vertical	-	-
6	Standing facing	Long	Dummy burned out.	
		Lateral		
		Vertical		
	Standing sideways	Long	9.75	17.75
		Lateral	55.0	12.75
		Vertical	-	-
7	Crouching facing	Long	4.75	6.25
		Lateral	8.75	4.25
		Vertical	5.75	6.75
	Crouching sideways	Long	3.0	6.75
		Lateral	6.75	24.0
		Vertical	8.25	5.75
8	Standing facing	Long	13.0	4.75
		Lateral	13.0	12.0
		Vertical	13.0	9.5
	Standing sideways	Long	4.75	3.25
		Lateral	2.75	3.0
		Vertical	6.5	2.5

FIGURE 1. THE DUMMY MAN

FIGURE 2. PRONE DUMMIES AT SITE Nº 1 BEFORE THE EVENT

FIGURE 3. DUMMIES AT SITE Nº 4 SHOWING THE VARIOUS POSTURES AND ORIENTATIONS, BEFORE THE EVENT

FIGURE 4. DUMMY AFTER DISPLACEMENT OF 42 ft FROM PRONE FACING POSITION AT SITE Nº 1

FIGURE 5 SITE Nº 4 AFTER THE EVENT

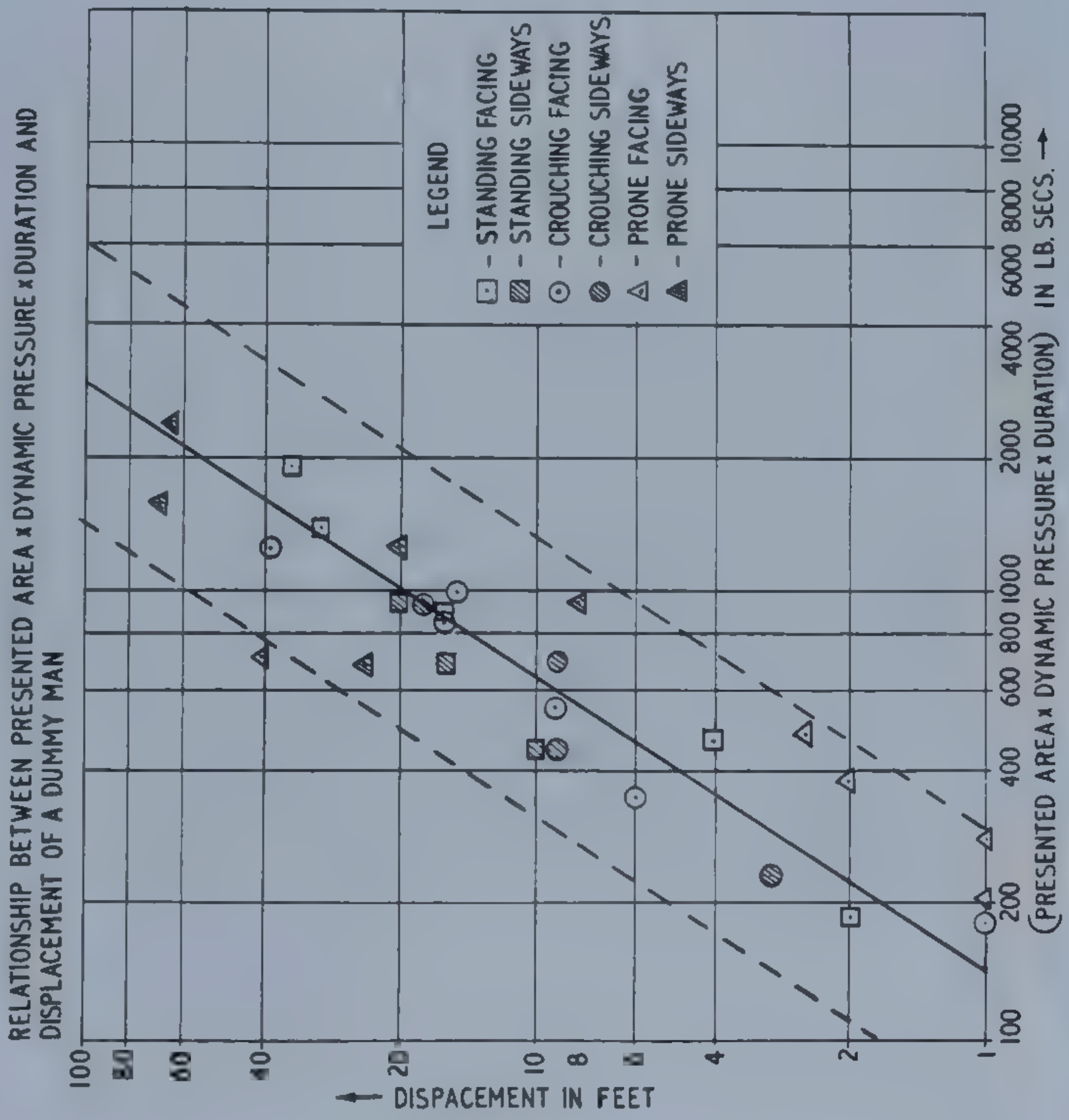


FIGURE 6. SHOWING THE RELATIONSHIP BETWEEN DISPLACEMENT AND (AREA PRESENTED × DYNAMIC PRESSURE × DURATION)

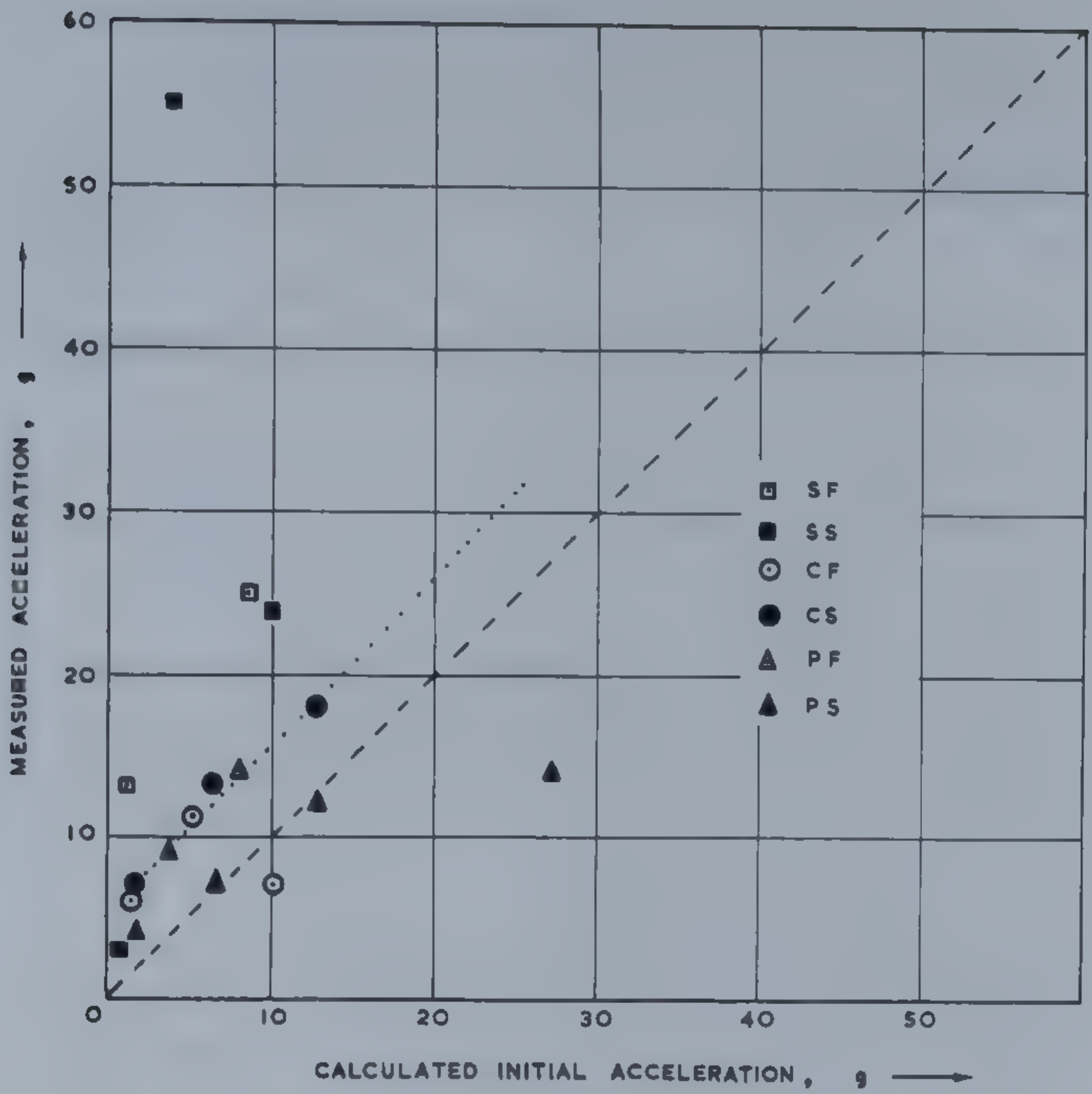


FIGURE 7. RELATIONSHIP BETWEEN CALCULATED AND EXPERIMENTAL RECORDS OF INITIAL ACCELERATIONS

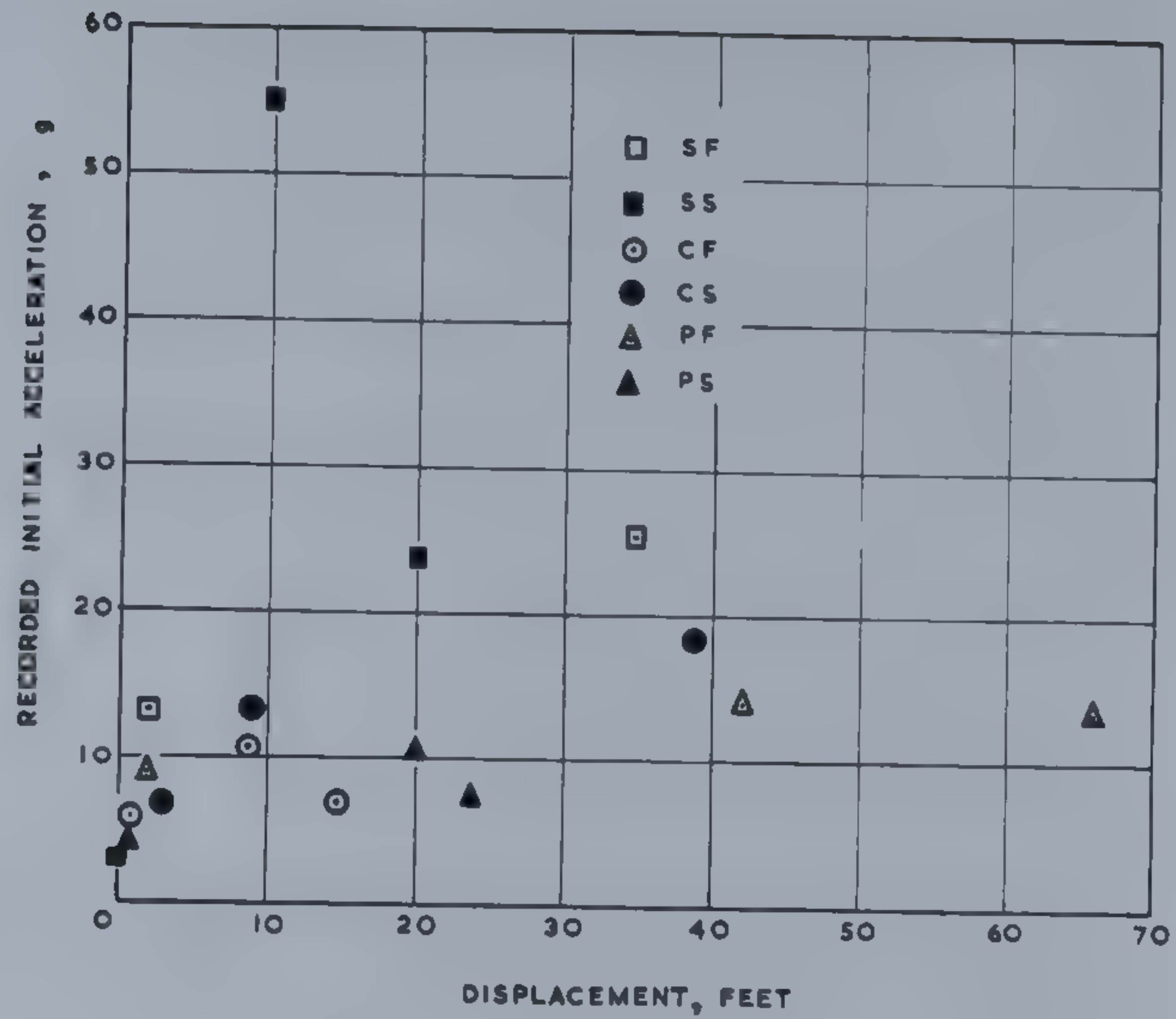


FIGURE 8. RELATIONSHIP BETWEEN EXPERIMENTAL RECORDS OF INITIAL ACCELERATION, IN PLACING OF TAKE-OFF AND DISPLACEMENT

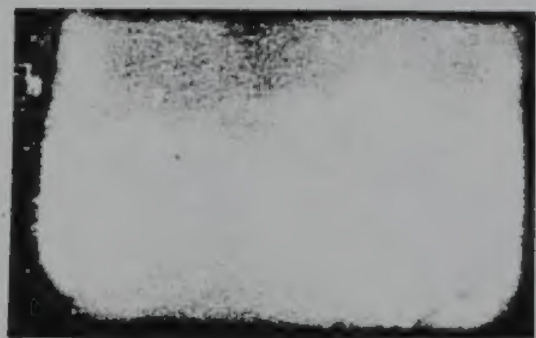
(1) THE SITE JUST BEFORE DETONATION

(2) FIRST LIGHT

(3) FIRST SIGNS OF SCORCHING ($^{11}/_{64}$ sec)

(4) OBVIOUS SCORCHING AND STEAMING OF BATTLEDRESS($^{11}/_{64}$ sec)

(5) SMOKING OF BATTLEDRESS AND OVERALL POPCORN EFFECT($^{32}/_{64}$ sec)



(6) FIELD OF VIEW COMPLETELY OBSCURED BY STEAM AND DUST (1 sec) THE BLAST WAVE DID NOT REACH THIS SITE UNTIL 0·54 SECONDS LATER

FIGURE 9. SELECTED FRAMES FROM THE CINEMATOGRAPHIC RECORD AT SITE Nº 6 64 FRAMES/sec

THE TOTAL HEAT DOSE WAS 23 cals/cm^2, γ radn 2000 r

(1) THE SITE JUST BEFORE DETONATION

(2) FIRST LIGHT

(3) BEGINNING OF SCORCHING (5/19 secs)

(4) STEAMING AND SMOKING OF BATTLE -DRESS, POPCORN EFFECTS OVER GROUND (9/19 secs.) NOTE BLACK SMOKE OBSCURING FACE OF DUMMY STANDING ON RIGHT, AND ALMOST COMPLETE OBSCURATION OF BOTH CROUCHING DUMMIES

(5) CONTINUATION OF SCORCHING OF GARMENTS (15/19 secs)

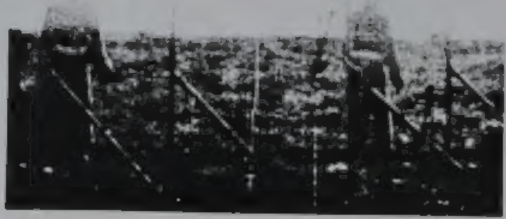
(6) EVENTS AT 1 SECOND

(7) EVENTS AT $1\frac{1}{2}$ SECONDS

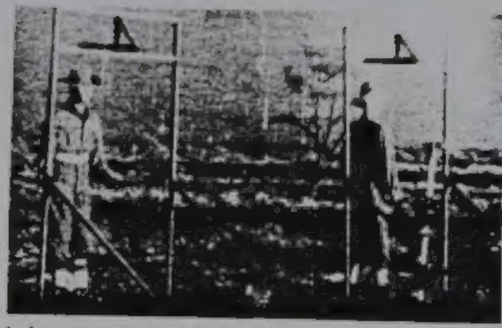
(8) COMPLETE OBSCURATION AT $1\frac{3}{4}$ SECONDS. THE BLAST WAVE REACHED THIS SITE 0·39 SECONDS AFTER THIS LAST VIEW

FIGURE 10. SELECTED FRAMES FROM THE CINEMATOGRAPHIC RECORD AT SITE Nº 7 19 frames/sec

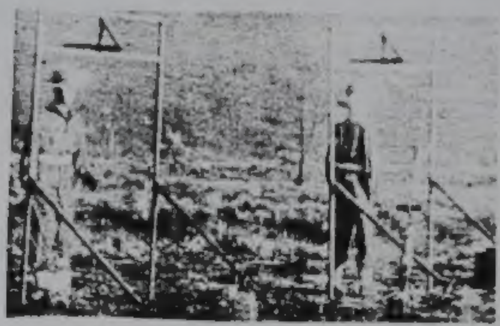
THE TOTAL HEAT DOSE WAS 14 cals/cm^2, γ radiation 34 or.



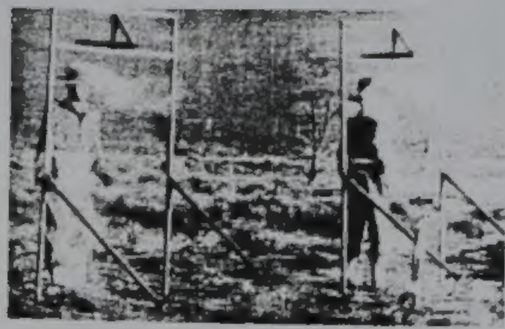
(1) SITE JUST BEFORE DETONATION



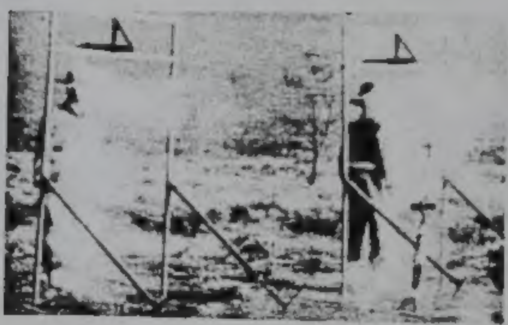
(2) FIRST LIGHT



(3) DETECTABLE SCORCHING OF HATS (5/19 secs)

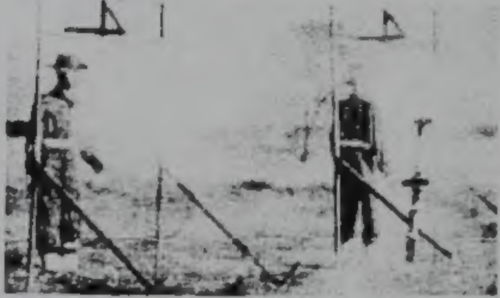


(4) FIRST DETECTABLE SCORCHING OF BATTLEDRESS (10/19 secs)

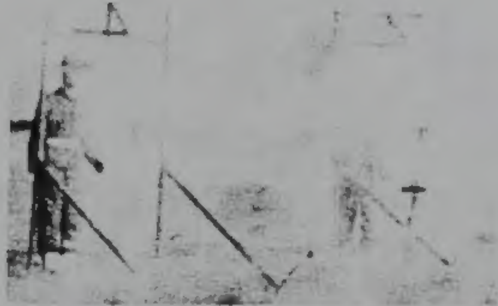


(5) GENERAL SCORCHING (15/19 secs)

(6) SCORCHING AND STEAMING FROM GROUND ($1\frac{1}{4}$ secs)



(7) STEAMING AT $1\frac{1}{2}$ SECONDS

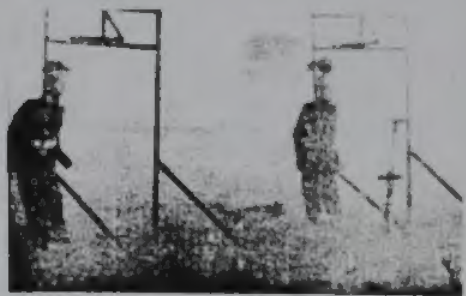


(8) GENERAL MISTINESS AT 2 SECONDS

FIGURE 11. SELECTED FRAMES FROM THE CINEMATOGRAPHIC RECORD AT SITE No. 8 (19 frames/sec)

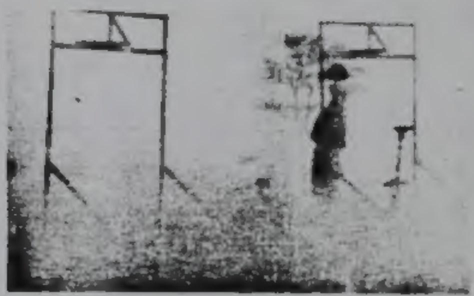
(9) VIEW JUST BEFORE ARRIVAL OF BLAST WAVE AT 3·7 SECONDS

(10) ARRIVAL OF BLAST WAVE (1/19 secs LATER). NOTE HATS

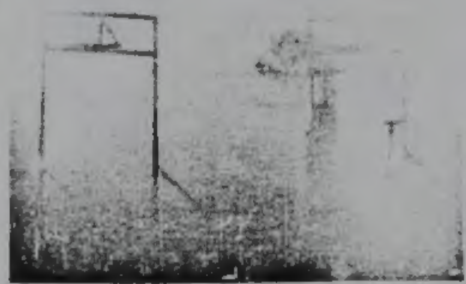


(11) MOVEMENTS 5/19 secs AFTER ARRIVAL OF BLAST WAVE

(12) MOVEMENTS 10/19 secs AFTER ARRIVAL OF BLAST WAVE



(13) MOVEMENTS 14/19 secs AFTER ARRIVAL OF BLAST WAVE



(14) GENERAL VIEW 1 SECOND AFTER ARRIVAL OF BLAST WAVE

(15) GENERAL VIEW $1\frac{1}{2}$ SECONDS AFTER ARRIVAL OF BLAST WAVE

FIGURE 11. (Contd) SELECTED FRAMES FROM THE CINEMATOGRAPHIC RECORD AT SITE No. 8 (19 frames/sec)

THE TOTAL HEAT DOSE AT THIS SITE WAS 5·9 cals/cm^2 AND γ radiation 17 r